# Trends of large scale direct shear strength results for LLDPE-HDPE geomembrane/soil interfaces

**José Ale,** AMEC, Peru

**Martín Rodriguez,** AUSENCO, Peru

**Claudio Román,** AMEC, Chile

**Humberto F. Preciado,** AMEC, Peru

**Marsy Sanchez,** AMEC, Peru

## Abstract

The mining industry is developing at a fast pace in the South America region, and demands the construction of important and larger mining structures such as: tailings impoundments, heap leach pads, rock waste facilities, etc. Heap leach pads by design, must contain leached mineral solutions through properly designed engineered liner systems. As part of the geotechnical design of a heap leach pad, a geotechnical characterization of the geomembrane-soil interface must be conducted. This characterization is performed by large scale direct shear (LSDS) testing, using confinement pressures which simulate the weight of the ore stacking in the leach pad. The types of geomembrane mainly used in the mining industry are the high and linear low density polyethylene (HDPE and LLDPE, respectively), single side textured (SST), and of variable thickness (1.5 and 2.0 mm).

Many authors have studied the responses of geomembrane-soil interfaces (Koener et al., 2005; Koerner et al. 2007; Thiel, 2009; Parra et al., 2010; Breitenbach, 2011), and analyzed their strength envelopes considering linear and nonlinear geometries (Parra et al., 2012). This paper compiles LSDS test results obtained in Peru, and other data available in the existing literature, and analyzes their trends and range of values. Results from HDPE and LLDPE single side textured geomembranes are presented, with the textured side in contact with the underlying soil, and using confinement pressures of up to 800 kPa, which are equivalent to about 45 m of ore stacking. The results show a consistent trend in the residual shear strength envelopes of different types of geomembranes, regardless of geomembrane thickness. For high pressures, this trend could be non-linear. The values of adhesion range from 26 to 53 kPa, and angles of internal friction range from 16° to 26° for HDPE interfaces, and adhesion between 15 and 35 kPa, and angles of internal friction between 12° and 24° for LLDPE interfaces.

## Introduction

The mining industry is developing at a fast pace in the South America region, and demands the construction of important and larger mining structures such as: tailings impoundments, heap leach pads, rock waste facilities, etc. The correct geotechnical design of these structures is extremely important due to their large size and the implications of their potential failure.

Heap leach pads must contain leached mineral solutions through properly designed engineered liner systems. The proper design of these systems requires proper characterization of the interface strength properties between geomembrane and soil. This characterization is performed by LSDS testing, using confinement pressures which simulate the weight of the ore stacking in the leach pad.

In Peru, leach pads are commonly located in areas where the irregular topography requires the design of grading with steep slopes and gradients. In light of this, the liner system becomes a potential plane where a translational or block sliding failure surface could occur. Therefore, it is extremely important to characterize the shear resistance of the liner system in the geotechnical design of a leach pad. The geotechnical design of a heap leach pad includes the completion of many geotechnical analyses and the characterization of materials which include: puncture tests, LSDS testing, slope stability and stress-strain analyses.

Slope stability analyses are performed considering circular, non-circular and translational slip surfaces. The circular and non-circular slip surface analyses evaluate stability associated with homogeneous and non-homogeneous soil conditions, respectively. Translational or compound slip surface analyses evaluate the possibility of landslides through the liner system of the leach pad.

Stress-strain analyses are usually required when the factors of safety from slope stability analyses have a low value (usually less than 1), either under static or seismic conditions. From these results, the designer must consider what type of geomembrane is most appropriate for the project (HDPE or LLDPE).

To ensure that the liner will not be perforated due to the gravel particles of the overliner, a puncture test should be performed, considering the same confinement to which the geomembrane will be subject during the mine operation. In order for this test to be representative, it is preferable to have reliable information about the anticipated or projected ore stacking height, the type and thickness of the geomembrane and the soil liner.

This paper describes the geotechnical design of a heap leach pad with emphasis on the liner system design, which covers laboratory testing and geotechnical analysis.

## Liner system of heap leach pad

In Peru, the heap leach pads usually have a conventional liner system, consisting of a soil liner (low permeability soil) covered by a geomembrane which in turn is covered by a gravelly material (overliner), as shown in Figure 1.

The soil liner has to be clayey and its hydraulic conductivity must be less than $5\times10^{-6}$ cm/s. The geomembrane is commonly made of polyethylene of high and linear low density (HDPE and LLDPE, respectively). These structures usually use geomembrane of a textured side and a smooth side (SST), where the textured side faces the clay soil liner and the smooth side faces the gravelly over liner material. The gravelly material generally has to have draining characteristics, and should not pinch the liner under confinement, which can reach pressures up to 4,000 kPa.

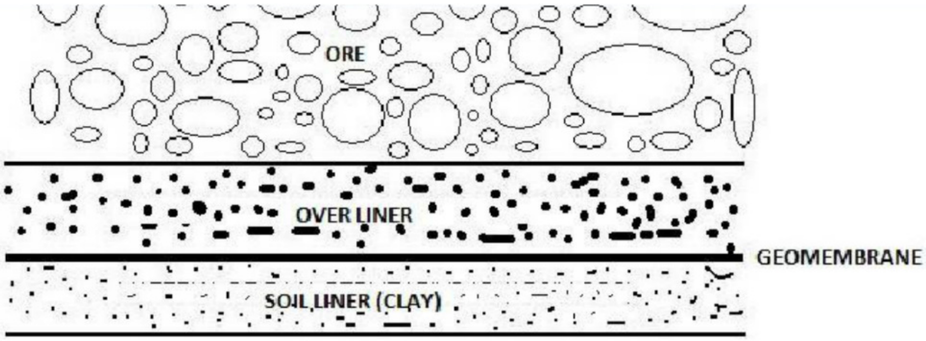

**Figure 1: Conventional liner system**

In cases where there is no clay material or where this cannot be placed (steep slopes), soil liner can be replaced by a geosynthetic clay liner (GCL), as shown in Figure 2. The GCL consists of a layer of bentonite confined by two layers of geotextile (woven or nonwoven). This geocomposite has a hydraulic conductivity of about $10^{-9}$ cm/s.

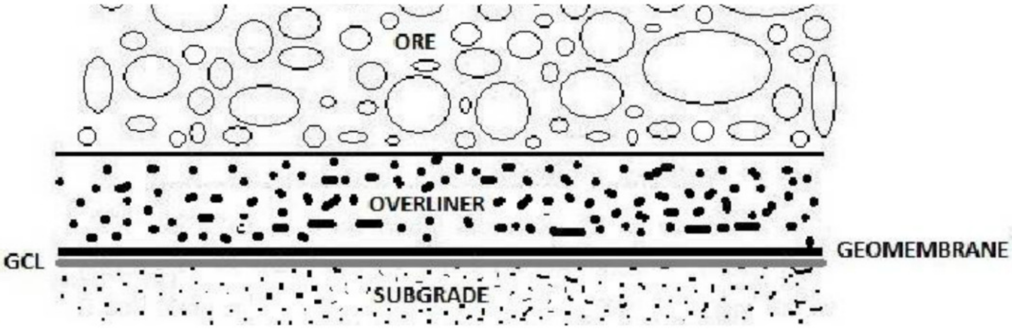

**Figure 2: GCL liner system**

## Geotechnical characterization of liner system

### General

This paper will focus on the geotechnical characterization of the conventional liner system. In this type of liner, there are two interfaces: geomembrane/soil-liner and geomembrane/overliner. Many authors have studied the behavior of geosynthetic interfaces (Koener et al., 2005; Koerner et al. 2007; Thiel, 2009; Parra et al., 2010; Breitenbach, 2011) and analyzed their linear and nonlinear geometry (Parra et al ., 2012). However, this paper shows LSDS test results grouped by type and thickness of geomembrane. Finally, these results are compared with each other.

### Geomembrane/soil interfaces analyses

In the case of a heap leach pad, the geotechnical characterization of the interfaces is carried out by performing direct shear tests on a large scale box (30 cm × 30 cm), following the methodology of ASTM D5321 standard. These tests can be performed including all the materials that form the lining system: gravelly material, geomembrane and clayey soil. The shear strength values obtained by this test depend on the resistance values of the geomembrane/gravel and geomembrane/clay interfaces (two variables).

Parra et al. (2010) studied the difference of values of the large scale direct shear (LSDS) test results considering the presence and the absence of a gravelly material (overliner) on the geomembrane. In the test, the overliner which must be in contact with the smooth side of the geomembrane was replaced by rigid substrata (concrete). The results of this comparison for the case of an LLDPE geomembrane showed that it is more conservative (lower residual shear stress values are achieved) to consider the presence of a rigid substrata than it is to consider a regular overliner material, as shown in Figure 3.

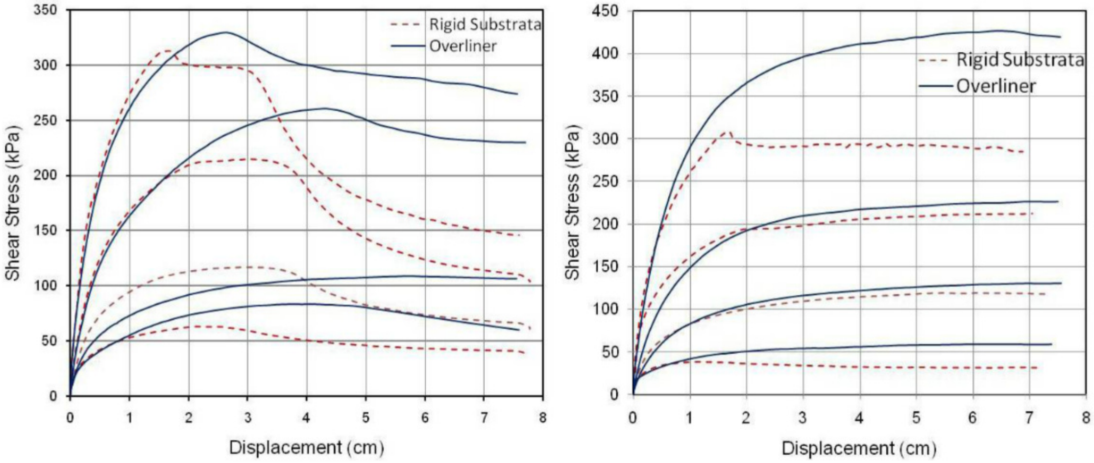

**Figure 3: LSDS tests performed with overliner and rigid substrata (Parra et al., 2010)**

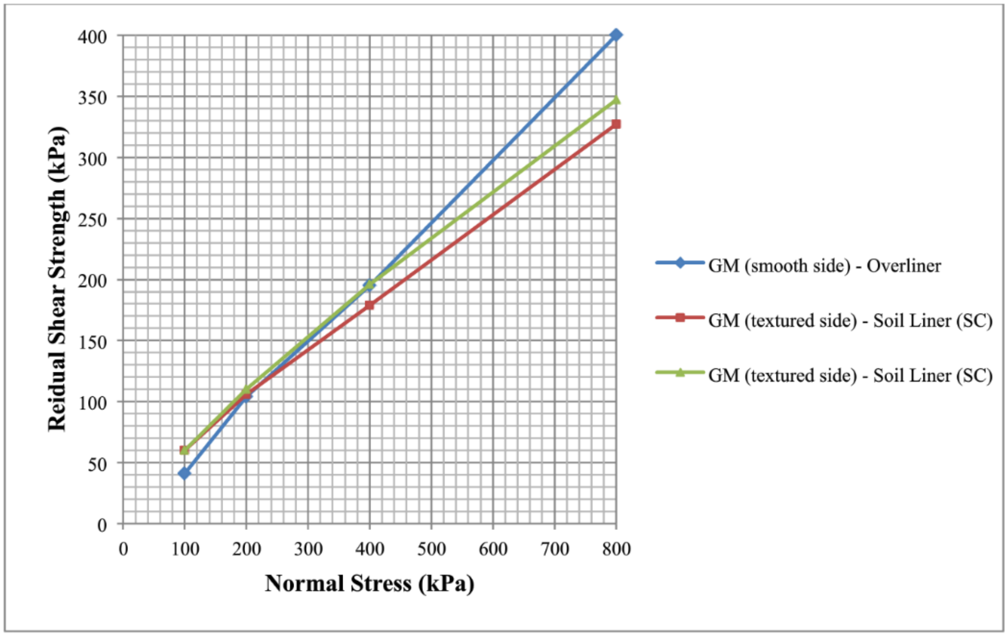

**Figure 4: LSDS in Geomembrane – overliner and geomembrane – soil liner interfaces**

Furthermore, comparing independently three results of LSDS tests from the interfaces of a liner system, it can be seen that the interface geomembrane/overliner (over the smooth side) has a higher residual shear strength than the interface geomembrane/soil liner (in contact with the textured side) for the same LLDPE 1.5 mm geomembrane (Ale et al., 2010) for normal stresses greater than 400 kPa, as shown in Figure 4.

From this, it appears that the geotechnical characterization and shear strength of the liner system of a heap leach pad depends on geomembrane/clay interface shear stress.

## Review of LSDS test results

In the geotechnical design of a heap leach pad, the physical stability of the structure must be analyzed. In common practice, the slope stability analysis considering a translational or block-slip surface (through the liner system) uses the residual values of the LSDS test in geomembrane-soil liner interface.

Taking this into consideration, results from 83 LSDS tests have been analyzed for LLDPE and HDPE geomembranes, of 1.5 mm and 2.0 mm thicknesses. All of these tests have been conducted in interfaces with soil liner (clayey material). The soil liner in all tests has been placed with a density of 95% of maximum dry density from the standard proctor (ASTM D698), with the optimum water content. The samples are saturated and then confined for two hours with the test pressure, before starting the test. A compilation of these test results is plotted in Figures 5, 6, 7 and 8. Table 1 then shows the average trend of strength parameters of the plotted data; in addition, the upper and lower boundaries for shear strength residual values are shown. In all cases the residual values of shear strength have been measured at 7.5 cm of horizontal displacement. These results are consistent with those reported by Koerner et al. (2005).

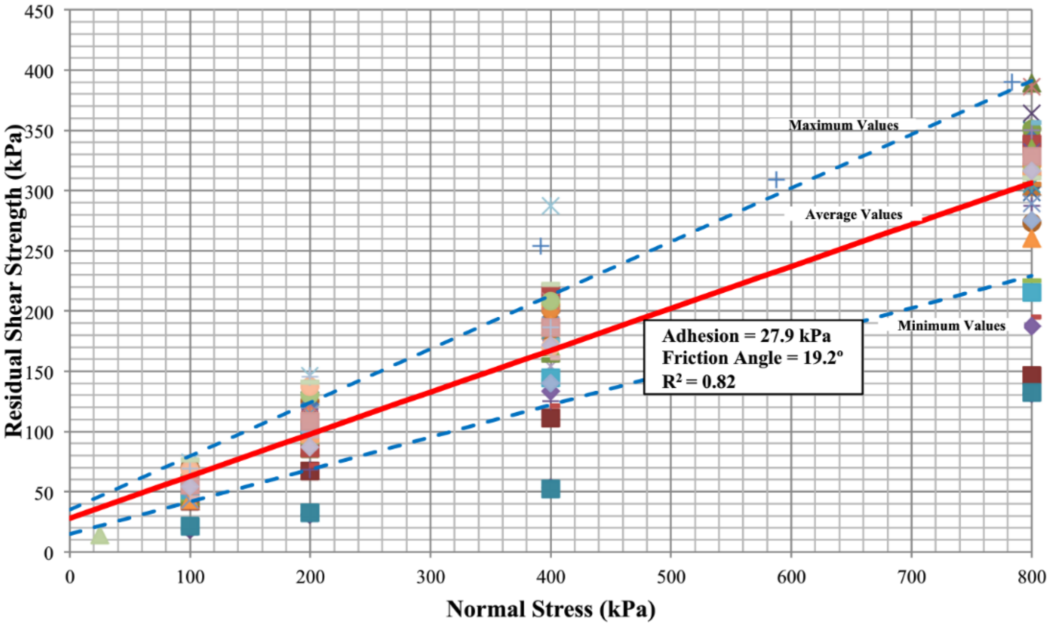

**Figure 5: LSDS tests in LLDPE geomembrane, 2 mm (residual values)**

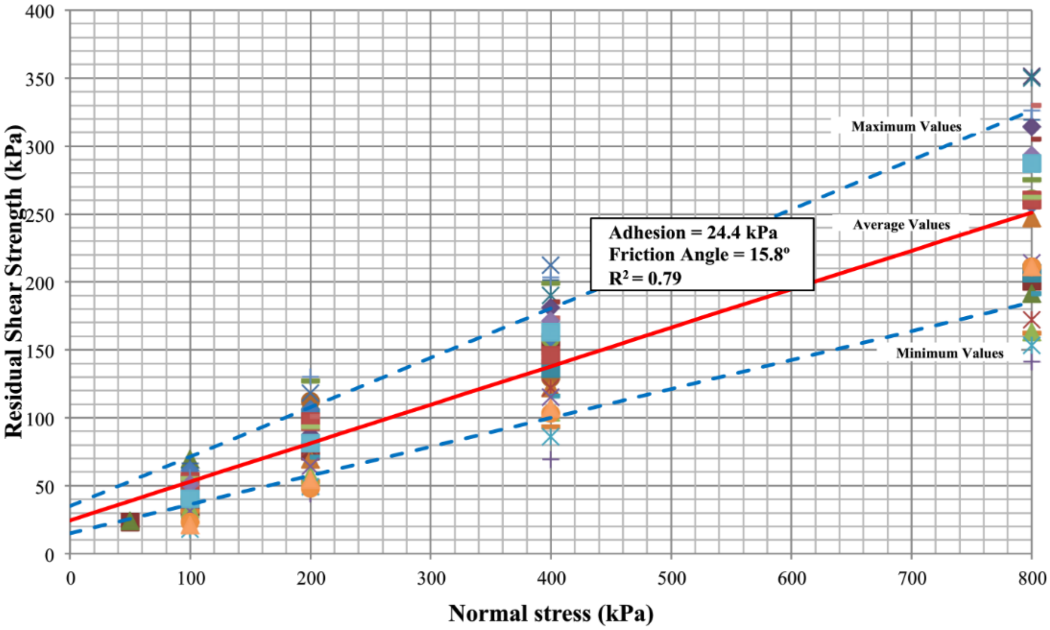

**Figure 6: LSDS tests in LLDPE geomembrane, 1.5 mm (residual values)**

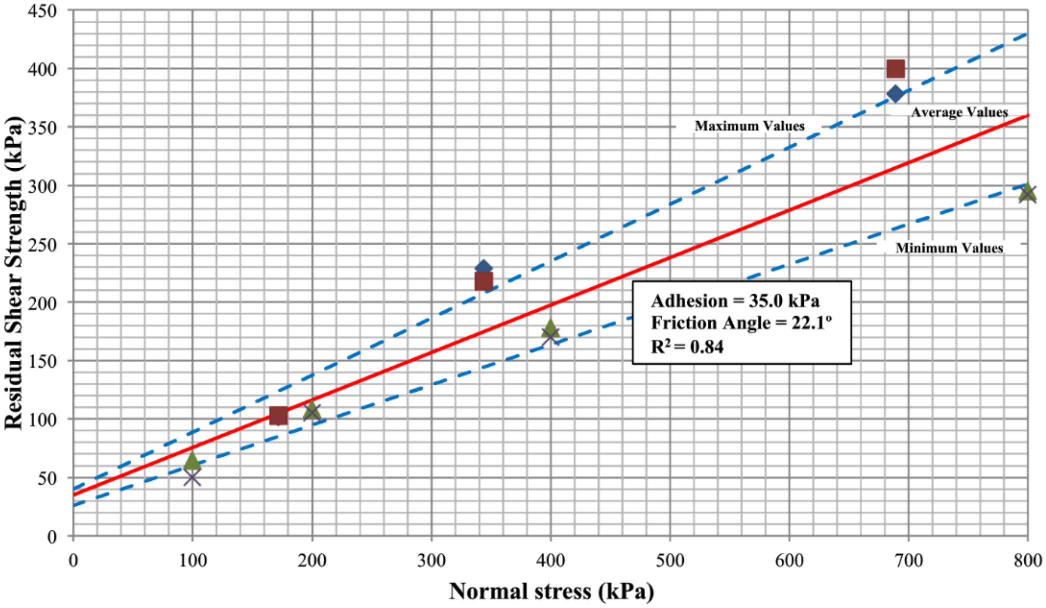

Figure 7: LSDS tests in HDPE geomembrane, 2 mm (residual values)

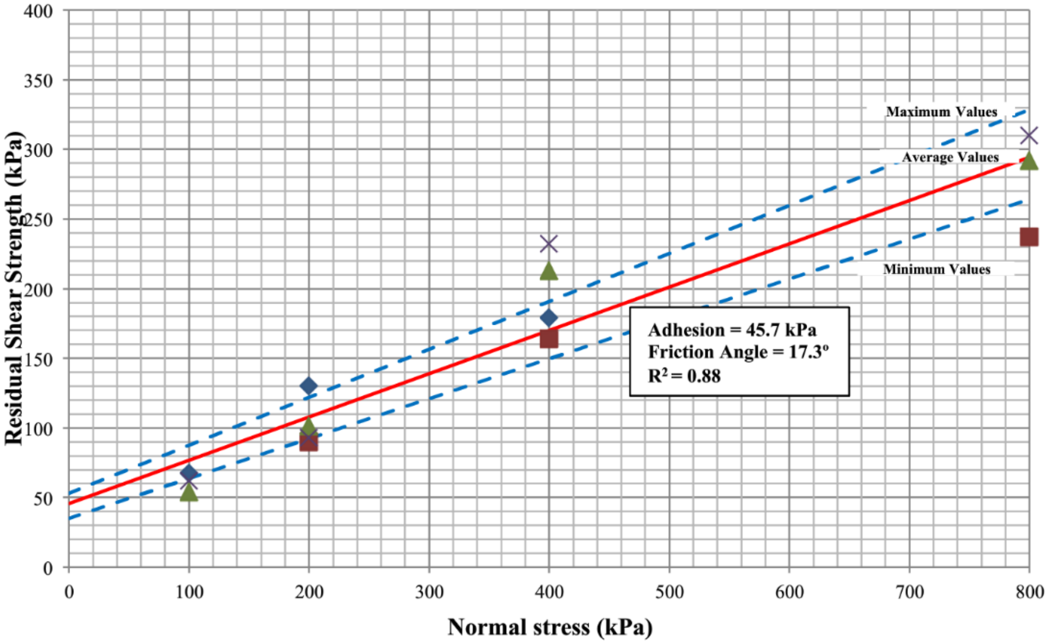

Figure 8: LSDS tests in HDPE geomembrane, 1.5 mm (residual values)

The available data from LSDS tests in HDPE geomembranes are much less than those from LLDPE, because in recent times, the use of LLDPE geomembranes in leach pads has been more widespread due to their flexibility, higher tensile break elongation, and resistance to puncture (Islam et al., 2011). For this reason, the data shown in Table 1, for LLDPE (75 tests) may be more representative than those of HDPE (8 tests). Figure 9 shows all values listed in Table 1.

**Table 1: Trends of shear strength parameters from LSDS tests**

| Geomembrane | Shear strength parameters | | | | | |
|---|---|---|---|---|---|---|
| | Average | | Maximum | | Minimum | |
| | Adhesion (kPa) | Friction angle (°) | Adhesion (kPa) | Friction angle (°) | Adhesion (kPa) | Friction angle (°) |
| LLDPE, 2.0 mm | 27.9 | 19.2 | 34.0 | 24.0 | 15.0 | 15.0 |
| LLDPE, 1.5 mm | 24.4 | 15.8 | 35.0 | 20.0 | 15.0 | 12.0 |
| HDPE, 2.0 mm | 35.0 | 22.1 | 40.0 | 26.0 | 26.0 | 19.0 |
| HDPE, 1.5 mm | 45.7 | 17.3 | 53.0 | 19.0 | 35.0 | 16.0 |

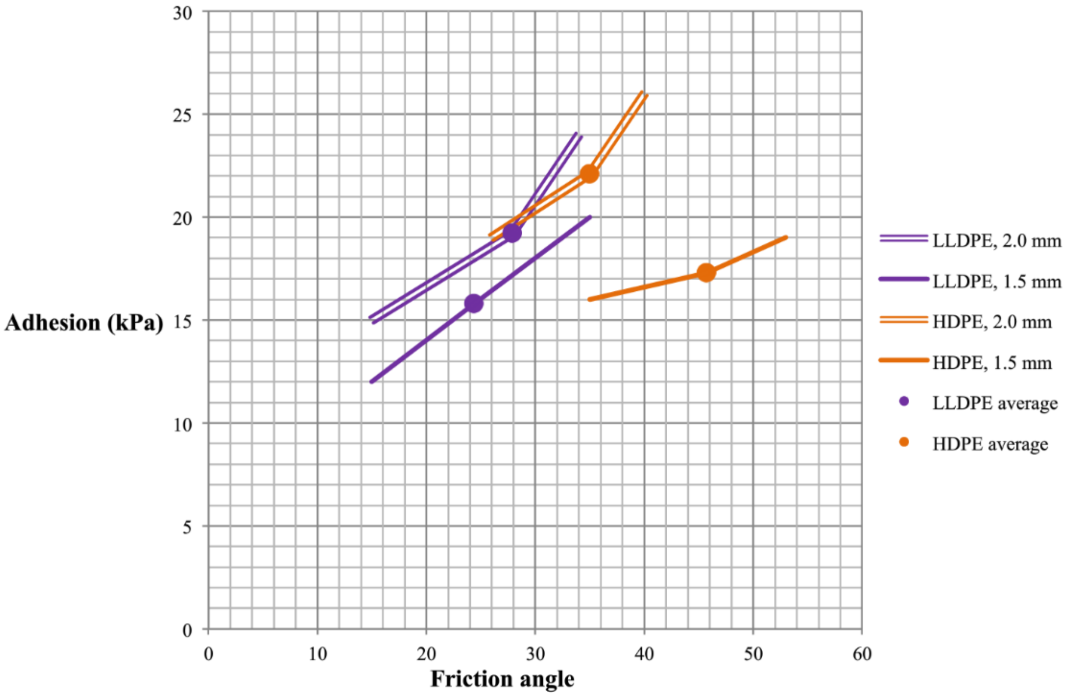

**Figure 9: Trends of shear strength parameters from LSDS tests**

## Influence of shear strength of liner system on slope stability

In order to analyze the influence of shear strength of interfaces on the physical stability of a heap leach pad, a hypothetical case is conducted by limit equilibrium method (Spencer method), considering a heap height of 100 m, and the slope of liner system varying between 0% and 4%, as shown in Figure 10. The analyses were performed inputting average, maximum and minimum shear strength parameters for a LLDPE geomembrane of 2 mm thickness. Table 2 summarizes the results of all of these analyses.

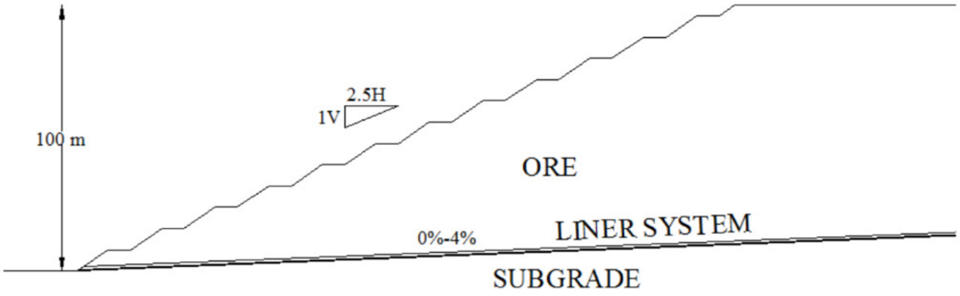

**Figure 10: Hypothetical heap leach analyzed**

**Table 2: Factors of safety for slope stability using 2 mm LLDPE geomembrane**

| Slope | Shear strength parameters | | |
|---|---|---|---|
| | Average | Maximum | Minimum |
| | Factor of safety | Factor of safety | Factor of safety |
| 0% | 1.73 | 1.93 | 1.52 |
| 1% | 1.71 | 1.89 | 1.51 |
| 2% | 1.70 | 1.88 | 1.49 |
| 3% | 1.69 | 1.87 | 1.46 |
| 4% | 1.67 | 1.86 | 1.45 |

## Conclusions

Results from a database of LSDS test performed on HDPE and LDPE geomembrane materials of different thicknesses, as well as other data available in the existing literature, show that the shear strength of the smooth side geomembrane/overliner interface is larger than that of the textured side geomembrane/soil-liner interface for confinement pressures over 400 kPa.

The database was compiled from tests where the soil liner had been placed at 95% of maximum dry density (standard proctor) and optimum water content. The samples were also saturated and then confined for two hours at the test pressure, before starting the test. In all cases the residual values of shear strength were measured at 7.5 cm of horizontal displacement.

Results from the database also support the conclusion that the physical stability in the block-slip surface or translational failure mode of most heap leach pads depend on the shear strength of the interface geomembrane/soil-liner, rather than the geomembrane/overliner interface.

The linear shear strength envelopes from the different geomembranes and thicknesses tests showed $R^2$ values of 0.82, 0.79, 0.84 and 0.88 for geomembranes of 2 mm LLDPE, 1.5 mm-LLDPE, 2 mm-HDPE, and 1.5 mm-HDPE, respectively.

The residual shear strength of 2 mm LLDPE geomembranes ranged from 15 to 34 kPa in adhesion and from 15º to 24º for friction angle. The average shear strength parameters were adhesion of 27.9 kPa and friction angle of 19.2º. Whereas for 1.5 mm LLDPE geomembranes, the residual shear strength ranged from 15 to 35 kPa for adhesion and from 12º to 20º for friction angle, with average adhesion of 24.4 kPa and friction angle of 15.8º.

The residual shear strength of 2 mm HDPE geomembranes ranged from 26 to 40 kPa for adhesion and from 19º to 26º for friction angle. The average shear strength parameters were adhesion of 35 kPa and friction angle of 22.1º. Whereas for 1.5 mm HDPE geomembranes, the residual shear strength ranged from 35 to 53 kPa for adhesion and from 16º to 19º for friction angle, with average adhesion of 45.7 kPa and friction angle of 17.3º.

In a hypothetical case example of a heap leach pad 100 m high, and using the results from the database presented in this paper for 2 mm LLDPE, the factors of safety range from a maximum of 1.93 to a minimum of 1.52 for 0% liner system slope and under static conditions.

## References

Ale, J., Clariá, J. and Bonalumi, A. (2010) Diseño Geotécnico de Pilas de Lixiviación. In *Proceedings of Congreso Argentino de Mecánica de Suelos e Ingeniería Geotécnica 2010*, Mendoza, Argentina.

ASTM D 5321 (2012). Standard test method for determining the coefficient of soil and geosynthetic or geosynthetic and geosynthetic friction by the direct shear method. West Conshohocken, Pennsylvania, USA: American Society for Testing and Materials.

ASTM D 698 (2012). Standard test methods for laboratory compaction characteristics of soil using standard effort (12,400 ft-lbf/ft$^3$ ft/ft-lbf/f$^3$)). West Conshohocken, Pennsylvania, USA: American Society for Testing and Materials.

Breitenbach, A.J. (2011) “Old-timer” recalls the history of geomembrane interface strength tests. Geosynthetics. Retrieved June, 2011 from http://geosyntheticsmagazine.com

Islam, M.Z., Gross, B.A. and Rowe, R.K. (2011) *Degradation of exposed LLDPE and HDPE geomembranes: a review*. Geo-Frontiers 2011 © ASCE 2011.

Koerner, R.M. and Koerner, G.R. (2005) Direct shear database of geosynthetic-to-geosynthetic and geosynthetic-to-soil interfaces. *GRI Report #30*. Geosynthetic Institute 475 Kedron Avenue Folsom, PA 19033 USA.

Koerner, R.M. and Koerner, G.R. (2007) Interpretation(s) of laboratory generated interface shear strength data. *GRI White Paper #10.* Geosynthetic Institute 475 Kedron Avenue Folsom, PA 19033 USA.

Parra, D., Soto, C. and Valdivia, R. (2010) Soil liner-geomembrane interface shear strength using rigid substrata or overliner. In *Proceedings of 9th International Conference in Geosynthetics* (pp. 747−750), Guarujá, Brazil.

Parra, D., Valdivia, R. and Soto, C. (2012) Analysis of shear strength non-linear envelopes of soil-geomembrane interface and its influence in the heap leach pad stability. In *Proceedings of Second Pan American Geosynthetics Conference & Exhibition GeoAmericas 2012*, Lima, Peru.

Thiel, R. (2009) *Cohesion (or adhesion) and friction angle in direct shear tests*. Geosynthetics. Retrieved April, 2009 from http://geosyntheticsmagazine.com.